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ABSTRACT

Examples of the use of a mathematical model to evaluate the future renewal and replacement, or maintenance requirements, of the college physical plant are provided. The model, which was developed at Stanford University, simulates actual conditions at a specific location and allows resource allocation to be based on a definable quantitative base. The approach is based on a concept of cyclical renewal and replacement. The age cohort or birthdate of the facility and subsystems were derived by using 5-year increments beginning with initial construction in 1891. Tables provide information on: the construction date of each facility (by type) along with the square footage of that facility; the life cycles and resulting costs of a building built in 1950 containing 10,000 square feet; the sum of the tables for each individual building and the total expected cost in millions (1980 dollars) for each of the categories listed by cohort; and four possible versions of the total annual cost of interior finishes and special equipment, and other subsystems (i.e., likely cost, optimistic cost, pessimistic cost, and smoothed cost). It is concluded that this model will serve as the basis for a program by which renewal needs are identified in a creditable manner. (SW)

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APPA TECHNICAL PAPER

BEFORE THE ROOF CAVES IN: A PREDICTIVE MODEL FOR PHYSICAL PLANT RENEWALL - Part II

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APPA Technical Paper

Before the Roof Caves In: A Predictive Model for Physical Plant Renewal—Part II

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Part I of this paper appeared in the July issue of APPA Newsletter *(pp. 7-10). The conclusion of this article appears below.*

Date of Facility Construction

The established concept is one of cyclical renewal and replacement. The age cohort or birthdate of the facility and subsystems becomes the starting point for life cycles of the established subsystem. Age cohorts were derived by using five-year increments beginning with initial construction in 1891 up to the present date. The task force identified the construction date of each facility (by type) along with the square footage of that facility (Figure 4). Task force members addressed the question of modernization by establishing the age cohort at the remodeling date. This was done only when the facility had been significantly remodeled by the installation of new subsystems.

Framework to Model: An Example

The data developed, which had been tailored to reflect the expected performance and cost of the physical plant, could now be used to simulate the wear-out and resulting replacement cost of Stanford's physical plant. Because of the large number of facilities and variables involved, the task force constructed a computer model to perform the detailed calculations.

The mechanics of the model may best be illustrated by a simplified example using a single building. Figure 5 illustrates the life cycles and resulting costs of a building built in 1950 containing 10,000 square feet. The example only addresses four subsystems: roofs, interior partitions, HVAC, and other. These subsystems have life lengths of 40, 30, 20, and 10 years, respectively. The associated cost of replacing these subsystems is assumed to be $12, $5, $10, and $2 per square foot (in constant dollars, respectively). This produces a $120,000 replacement requirement each time the roof fails, a $50,000 requirement each time the interior partitions wear out, a $100,000 requirement each time the HVAC systems need replacement, and a $20,000 requirement as other items fail. These values are found by multiplying the cost per square foot by the total number of square feet in the building (10,000 square feet).

The life lengths are then used to determine where the replacement costs fit into the table. For instance, roofs are assumed to fail every 40 years. Since the building was built in 1950, the roof will fail for the first time in 1990 (1950 + 40) and every 40 years thereafter (2030 and 2070). Similar calculations were made for the other subsystems in the example.

After each of these values has been incorporated into the table, the total for each year was found by summing the appropriate row. For instance, the year 2010 row includes $50,000 for interior partitions, $100,000 for HVAC and $20,000 for other, adding up to a total projected maintenance requirement of $170,000 for the year 2010.

The Stanford University physical plant has a total of 218 academic buildings, which were built between 1891 and the present. For each of these buildings, the task force constructed a table similar to the previous example, using five-year intervals and containing the subsystems actually installed with

Figure 4: Stanford Building Categories by Life and Age Cohort

	COHORT	High Intensity Labs A	Library, Office, Classroom, Low Intensity Labs, Athletics B	Patient Care C	Misc. D	Residential R
1	1891-1895	3- 8,603	5- 126,031			1- 780
2	1896-1900	1- 1,052	1- 2,746			1- 527
3	1901-1905	2- 69,373	8- 124,311			
4	1906-1910	1- 38,871	1- 6,703			
5	1911-1915		2- 27,653			
6	1916-1920		12- 187,514	1- 624	2- 2,400	3-18,482
7	1921-1925				1- 3,400	
8	1926-1930	2- 18,506	2- 10,200		2-21,529	
9	1931-1935				1- 5,408	
10	1936-1940	1- 1,032	4- 254,828		6-17,173	3-12,145
11	1941-1945	----------NOTHING BUILT----------				
12	1946-1950	2- 45,691	3- 83,925			
13	1951-1955	2-110,516	3- 26,413		2- 900	
14	1956-1960	4- 72,417	14- 259,594		3-11,177	1- 3,292
15	1961-1965	5-176,527	17- 415,283		6-13,608	1- 2,177
16	1966-1970	8-489,743	22- 971,871	1-26,538		1- 858
17	1971-1975	3- 17,108	31- 208,497		2- 2,398	1- 1,000
18	1976-pres	7-196,077	13- 829,648			

Note: In each column, the digit to the left of the dash indicates the number of buildings built during that cohort; the digits to the right of the dash indicate the square footage.

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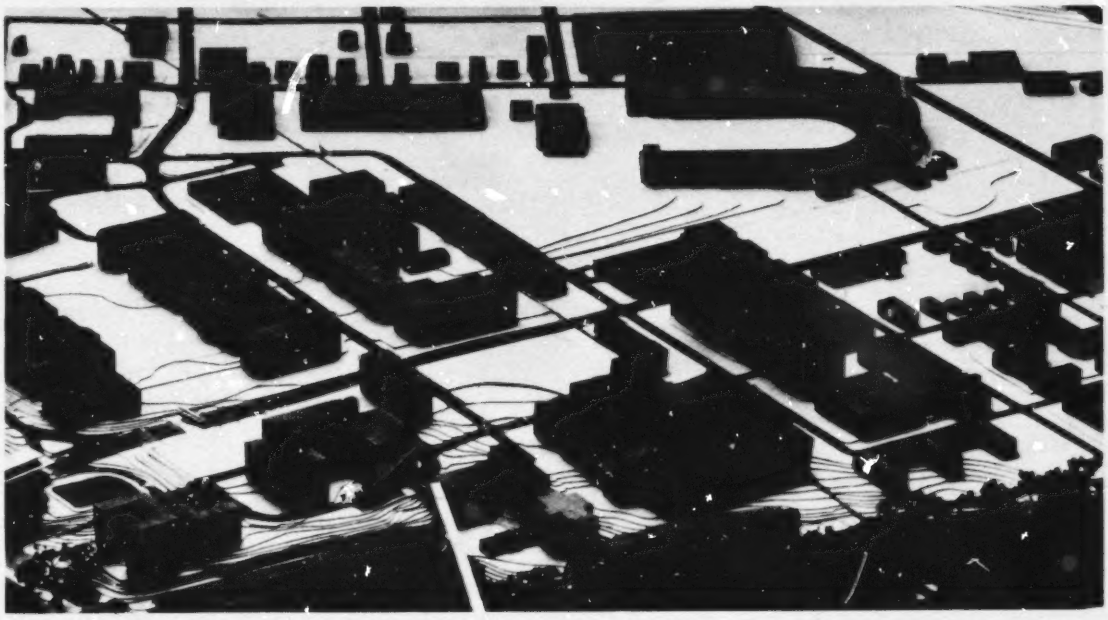

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each building. The tables were then summed to calculate the total expected cost for the physical plant renewal/replacement at Stanford University over the next 100 years.

Inspecting the Results

As with any results derived from a model, the first consideration is—are the results reasonable? This can only be answered after the results have been carefully inspected, the important variables identified, and the relative size of the variables compared. To help with this inspection, tables like Figure 6 were prepared. Figure 6 represents the sum of the tables for each individual building and identifies the total expected cost in millions (1980 dollars) for each of the categories listed by cohort. The bottom two rows are the column averages and the percent of total costs, respectively.

A quick inspection of the bottom line indicates that the most expensive subsystems are interior finishings with 31 percent for the total cost, HVAC with 26 percent, electrical with 14 percent, and special equipment with 10. The other subsystems each represent less than 10 percent of the total expected cost.

The task force analyzed these values to determine whether or not they were reasonable by reexamining past wear-out data to determine relative costs. They concluded that interior finishing and special equipment were slightly higher than expected but justifiable because of the prevalent practice of unreported supplemental funding for each of these categories.

Overall, the task force concluded that the results were reasonable. Because both interior finishings and special equipment were potentially deferrable, they were separated from the other costs in the final projections. Identification in this manner would allow additional funding options. This option to defer is not available in the other categories such as roofs or electrical systems, as failure of these subsystems would mandate immediate replacement.

The task force then prepared a graphic representation of total cost, separating interior finishings and special equipment. The results are illustrated by Figure 7, "Facilities Forecast—Likely." "Likely" correlates to the *likely* estimates of subsystem life lengths. Examining this graph reveals that the total expected annual cost will increase relatively slowly until the early 1990s, when we can expect a sharp increase. This increase occurs even after disregarding the two deferrable subsystems mentioned above.

This large projected replacement requirement is supported by the tremendous growth that occurred in Stanford's physical plant from 1955 to 1970. Over 50 percent of the existing plant was constructed during this 15-year period. It is reasonable that Stanford will be faced with a large liability starting in 1990 as this group of facilities begins to require extensive renewal/replacement.

The results obtained were also compared to the results of other methodologies for maintenance budgeting. In particular, they were matched against the most commonly accepted formula funding methodology, that of using a fixed percentage of the current replacement value (CRV) of the plant. While different sources cite various values ranging up to 3 percent of the plant

Figure 5: A Simplified Example*

Year	Roofs 40-year life $12/sq. ft.	Int. Part. 30-year life $5/sq. ft.	HVAC 20-year life $10/sq. ft.	Other 10-year life $2/sq. ft.	Total
1960				$20	$ 20
1970			$100	$20	$120
1980		$50		$20	$ 70
1990	$120		$100	$20	$240
2000				$20	$ 20
2010		$50	$100	$20	$170
2020				$20	$ 20
2030	$120		$100	$20	$240
2040		$50		$20	$ 70
2050			$100	$20	$120
2060				$20	$ 20
2070	$120	$50	$100	$20	$290
2080				$20	$ 20

All dollar values are in thousands of 1980 dollars.

* This example assumes that a building was built in 1950 with the above characteristics. It also assumes that the building contains 10,000 square feet.

Figure 6: Total Cost Over 5-Year Period in Millions of 1980 $

Year	Roofs	Finish	Plumb.	HVAC	Elect.	Sp. Eqp.	Other*	Total
1980	1.2	15.4	0.2	5.8	0.4	2.0	1.7	26.7
1985	1.0	8.1	0.0	12.4	1.2	1.5	1.1	25.3
1990	1.3	21.8	0.9	4.6	3.4	2.3	1.0	35.2
1995	2.7	8.1	0.4	13.7	3.0	4.5	2.0	34.3
2000	5.9	21.8	0.5	13.3	6.3	11.6	3.2	62.7
2005	0.9	8.1	0.9	5.3	12.9	1.6	4.9	34.6
2010	4.7	21.8	1.3	15.7	6.4	9.1	8.5	67.4
2015	1.0	8.1	2.1	16.5	10.9	1.5	2.4	42.4
2020	1.3	21.8	7.1	15.0	6.9	2.3	9.3	63.7
2025	2.7	8.1	0.9	15.0	3.3	4.5	1.1	35.6
2030	5.9	21.8	4.8	20.2	6.4	11.6	1.2	71.9
2035	0.9	8.1	0.0	4.0	5.9	1.6	1.0	21.5
2040	4.7	21.8	0.9	14.0	12.8	9.1	5.3	68.5
2045	1.0	8.1	0.4	12.7	5.6	1.5	3.6	32.9
2050	1.3	21.8	0.5	4.9	9.3	2.3	9.1	49.1
2055	2.7	8.1	0.9	14.6	2.2	4.5	3.2	36.1
2060	5.9	21.8	1.3	14.8	3.8	11.6	10.0	69.2
2065	0.9	8.1	2.1	8.1	4.6	1.6	5.5	30.9
2070	4.7	21.8	7.1	24.4	11.7	9.1	11.8	90.5
2075	1.0	8.1	0.9	14.0	12.7	1.5	2.7	40.9
2080	1.3	21.8	4.8	11.7	9.0	2.3	11.1	61.9
Ave.	2.5	15.0	1.8	12.4	6.6	4.7	4.7	47.7
%	5%	31%	4%	26%	14%	10%	10%	100%

* Includes foundations, interior partitions, elevators, fire protection, and exterior cladding.

CRV [reference 8], the most commonly cited value for budgeting purposes is an annual maintenance budget of 1.1 percent of the plant CRV [reference 9].

Expressing the Stanford University results of Figure 7 in CRV percentages yielded values from 1.5 to 2.6 percent of the Stanford plant CRV. These values are well within the range of the cited values. While the percent of CRV is a general benchmark, the model provides a more accurate forecast of future conditions (life cycle, building complexity, construction materials, and cost) at a specific location.

Sensitivity Analysis

The task force then performed a sensitivity analysis by varying the subsystem life length values, using the appropriate *optimistic* and *pessimistic* life length values discussed earlier and shown in Figure 2. Figures 8 and 9 show the respective results of these facilities forecasts. They help complete the picture of potential costs to the university.

As expected, the comparisons between Figures 7, 8, and 9 indicate that the greatest similarity exists between the *likely* and *optimistic* forecast. This is a result of the values assigned to the subsystem life cycles based on past performance at Stanford.

The *likely* and *optimistic* scenarios are not wildly different indicating that costs are unlikely to be much less than those indicated in the *likely* forecast. On the other hand, the large difference between the *likely* and *pessimistic* scenarios indicate that the potential costs could be considerably larger than expected.

The Cyclical Nature of the Forecast

Upon initial inspection, the extremely cyclical nature of the expected costs, as depicted by Figure 7, was difficult to interpret. However, further analysis has revealed that Stanford had built its buildings in cycles. Comparing the total buildings constructed in the first half of decades with those constructed in the last half of decades (for example, 1930–35, 1960–65, vs. 1935–40, 1965–70) revealed the astounding fact that over 70 percent of Stanford's buildings were constructed in the last half of each decade. This surprising discovery, in conjunction with the known fact that over 75 percent of the buildings were constructed post-1955, explained the cyclical nature.

Discovering the reason, however, does not solve the problem of planning and budgeting for such large fluctuations and we decided to smooth the model output for budget planning pur-

Figure 7: Facilities Forecast—Likely

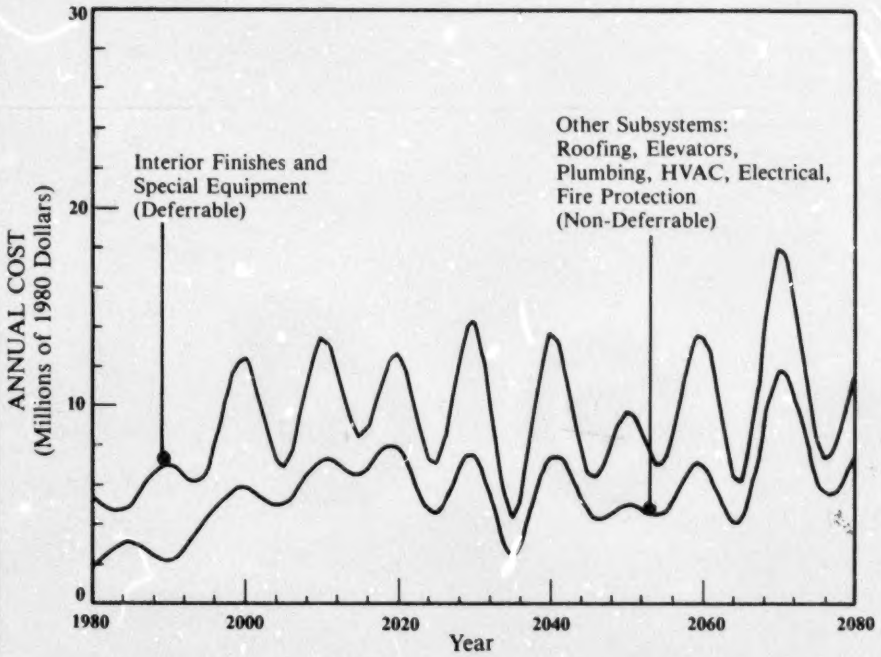


Figure 8: Facilities Forecast—Optimistic

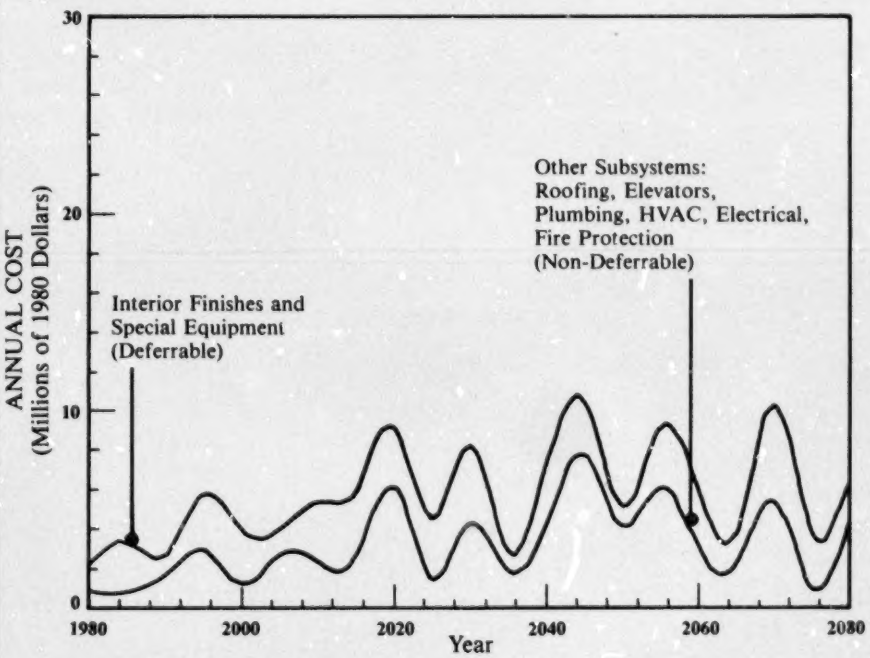


Figure 9: Facilities Forecast—Pessimistic

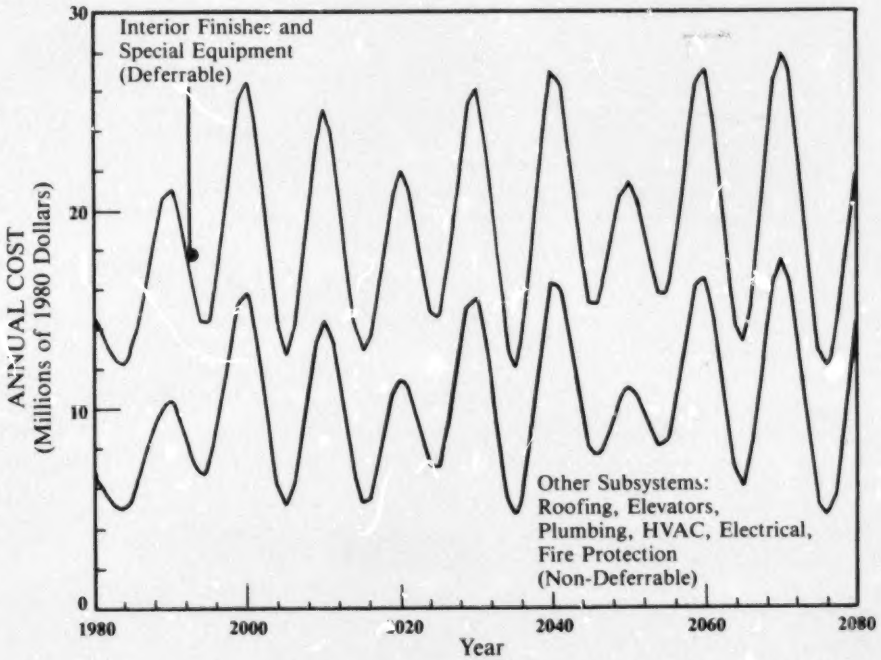
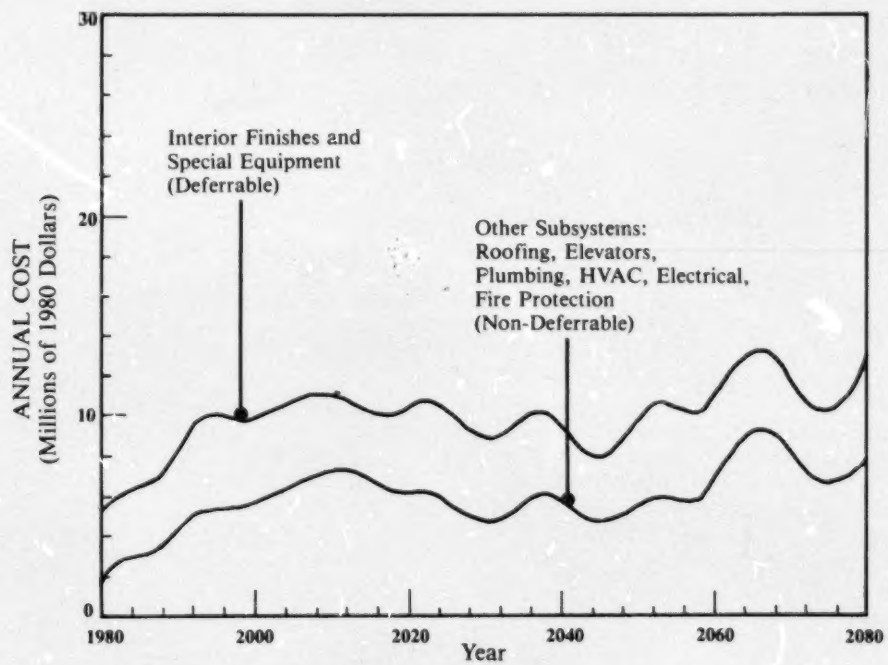


Figure 10: Facilities Forecast Likely (Smoothed)



poses. The results of this smoothing are illustrated by Figure 10. The smoothing was accomplished by using a two cohort moving average. The effect this smoothing had on the assumptions is that the cost of replacing a worn-out subsystem is now spread over the ten-year interval surrounding the expected wear-out date rather than the five-year interval used in Figures 7, 8, and 9.

Note that in Figure 10 the cycles still do occur, but they are greatly reduced. It is the feeling of the task force that these cycles are inherent in the building data and any further smoothing would be unrealistic.

Using the Results

A mathematical model of this type provides the planning and budgeting administrator with an accurate and effective tool for evaluating the future renewal and replacement, or maintenance, requirements of the physical plant. It is a tool that simulates actual conditions at a specific location. It allows resource allocation to be based on a definable quantitative base. The flexibility of this model permits the future maintenance liability of new plant additions to be evaluated before commitment. This feature raises maintenance to a new level of consciousness in that it forces a realization of future liabilities and identifies the commitments necessary to support them. As a planning tool, it provides the administration with a method by which to identify inordinately large funding requirements in outlying years and take the necessary action to meet those identified needs.

Stanford University has adopted this methodology as an integral part of the university's "Facilities Plant and Funding Forecast." University administrators believe that the established model affords a reasonable level of confidence in forecasting future renewal needs of the physical plant. Hence the decision has been made to move in the direction of a fully funded physical plant renewal program. This will be accomplished gradually over the next eight years.

While the established model will permit the administration to more effectively manage available resources, its single most important value lies in that it serves as the basis for a program by which renewal needs are identified in a creditable manner. A program of this type allows the establishment of a benchmark against which funding levels may be consistently evaluated.

While most universities have construction programs and space allocation programs, few have formally addressed the need for plant renewal on a consistent basis. A program of this nature will fill the gap in providing the necessary comprehensive facilities management plan.

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This paper was originally published by the National Center for Higher Education Management Systems in *Higher Education Planning and Budgeting: Ideas for the 80's*.

Improved Scheduling: Improved Service

Improved work scheduling of daily, weekly, monthly, and annual needs has enabled Boston College to improve its housekeeping routines. At the same time the housekeeping staff has assumed additional innovative housekeeping service programs.

Three years ago the campus housekeeping services reorganized. Before the reorganization, cleaning *other than* daily vacuuming, floor washing, trash removal, and restroom maintenance had been provided only upon request. This approach made for a never-ending battle with varying workloads and cleaning results.

To improve worker morale and reduce customer complaints uniform standards and controls were needed. We began by developing a system that differentiates between daily cleaning and special periodic cleaning.

The main feature of this reorganization was a new definition of the daily cleaning format. We did this in order to free existing work positions for use on prescheduled cleaning crews. The housekeeping department also decided that these newly formed crews could perform more efficiently during evening and late-night hours rather than during day-time hours.

We had to sell this new cleaning approach to others on campus by convincing them that the new schedule would improve service. Selling the program involved three initial steps:

1. Developing trust among campus residents,
2. Promoting the overall benefits in terms of cleaning cost and time, and
3. Establishing a channel of feedback from campus users to the housekeeping department.

Through a combination of tenant requests and our own planning research new programs have been instituted. One such program is the in-house pest extermination service.

Outside contractors had been responsible for pest extermination on a somewhat random basis. Insects easily relocated and repopulated in other areas that the contractor did not service. The housekeeping department requested responsibility and appropriate funding for this task, and received both.

During student vacation periods entire areas receive attention. Fumigation and application of residual powder complete the two-step process.

All of these programs include the tenant or consumer as a participant in the housekeeping process. "Customer satisfaction" has improved the self-image of the housekeeping staff at Boston College. Worker morale has improved, absenteeism is down, and work is accomplished effectively.

Walter Greaney
Housekeeping Manager
Boston College,
Chestnut Hill, Massachusetts

Job Corner *(cont. from p. 6)*

sity or college. Additional experience beyond five years, which has demonstrated successful application of the educational requirements may be substituted for up to two years on a year-for-year basis. Salary range: $31,884 to $38,508 annually (1981–82). Closing date August 23, 1982 with anticipated date of hire October 1, 1982. Applicants should submit a resume and at least three professional references. Address applications, nominations, and inquiries to Edward C. Del Biaggio, chair, Director of Plant Operations Selection Advisory Committee, Humboldt State University, Arcata, CA 95521. *An equal opportunity, affirmative action employer.*

HEARS Increases Physical Plant Job Bank

Since the beginning of fiscal year 1982, the Higher Education Administrative Referral Service (HEARS) has received 377 physical plant job openings, has searched 75 positions, and has increased the registrant bank to 797 persons.

As of May 1982, HEARS has the following numbers of registrants on file:

Architectural Services	45
Building Maintenance	123
Custodial Services	72
Energy Conservation	92
Engineering Services	66
Facilities/Construction	154
Physical Plant	176
Groundskeeping	69

Seeking an Overseas Assignment?

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For more information, write Daniel Heyduk, director, RISE, Institute of International Education, 809 United Nations Plaza, New York, NY 10017.